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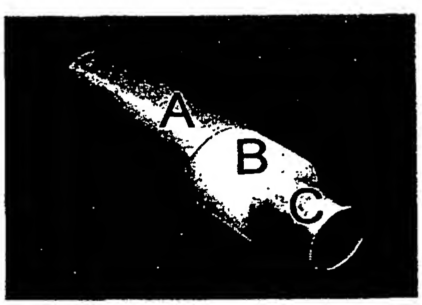
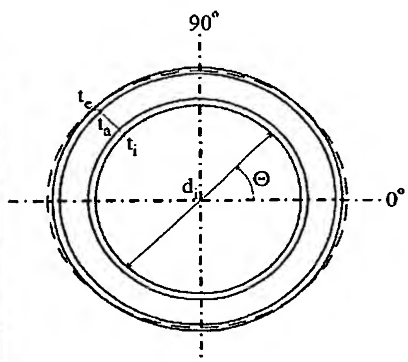
[Continued on next page]

(54) Title: SANDWICH PIPES FOR ULTRA-DEEP WATERS

(57) Abstract: This invention comprises a sandwich pipe, which consists of a tubular rigid system with three superposed layers (A, B, C), thermal and mechanical functions, to be used for the transportation of warmed hydrocarbons or general fluids in ultra-deep waters.



(a)



(b)

D_i (mm)	t_i (mm)	σ_{ui} (MPa)	t_e (mm)	σ_{ue} (MPa)	t_a (mm)	P_{co} (Mpa)
45.91	1.62	199.79	1.62	200.93	11.29	43.35
47.10	1.63	195.20	1.65	192.10	11.13	34.09
47.40	1.68	180.71	1.47	141.57	4.23	10.98
47.37	1.67	180.71	1.47	141.57	4.30	12.11
46.28	1.68	186.82	1.62	206.52	11.26	37.64
46.52	1.62	194.37	1.61	206.52	11.10	31.14
46.54	1.70	186.82	1.46	141.57	4.62	20.31
46.65	1.69	186.82	1.49	160.37	4.69	17.13

Table 1

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SK, SL, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZM, ZW.

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For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

Patent Report of the Invention of "Sandwich Pipes for Ultra-Deep Waters"

Technical Application

The innovative conception is basically a sandwich rigid pipeline specially designed for the transportation of warmed hydrocarbons or general fluids in ultra-deep waters.

Technical Review

Pipe-in-pipe conceptions for the transportation of hydrocarbons have been employed in the offshore petroleum industry. In general, such structures are selected with the aim to increase the insulation capacity in relation to single wall pipelines or bundles. The annulus material is dimensioned to reduce the thermal transferring between the exported fluid and the environment while the outer and inner pipes are designed to withstand the combination of internal and external pressure, tension and bending loads. This research project studied different conceptions of sandwich pipes, that fulfill concomitantly both the requirements of mechanical strength and thermal insulation.

Justification of the Invention

The conception of the sandwich pipe (SP) studied is composed of two concentric steel pipes in which the annulus is filled with an alternative insulating material. Its

geometry is schematically shown in Figure 1 (b), where D_i is the internal diameter of the inner pipe, t_i is the inner pipe thickness, t_a is the annulus thickness and t_e is the outer pipe thickness.

Sandwich structures composed of an intermediate material with low density, low thermal conductivity and inferior mechanical strength in relation to the outer and inner layers, are feasible alternative conceptions to conventional structures. It can be obtained by combining a thick intermediate layer and thinner adjacent layers with a good adherence among them. The inner and outer layers are designed to provide axial and flexural rigidities, while the intermediate layer must provide adequate thermal insulation, avoid sliding between adjacent layers and keep the inner layer away from the outer during the loading.

Therefore, three different materials were selected to evaluate, through different geometries, the feasibility of sandwich pipes: high strength steel for the inner and outer layers, and cement or polypropylene for the annulus. Due to its mechanical properties, extensive application in the offshore industry and the facilities provided for large scale production in Brazilian industry, the high strength steel was naturally considered for the analyses. The cement was

selected because it can be easily manufactured at a low cost, presents relatively low thermal conductivity and high compressive strength. However, it is a fragile material, favorable to nucleation of flaws and crack propagation during the manufacturing process or mainly when subjected to tension loads. On the other hand, the addiction of proper chemical components may increase its toughness. The polypropylene is a hyperelastic material (elongation of approximately 300%) with low thermal conductivity, but an inferior compressive strength in relation to the cement. Furthermore, it is an expensive raw material and requires a sophisticated SP manufacturing process.

Certainly, there are many combinations of materials and geometries that can fulfill the thermal and structural requirements. The overall submerged weight, the raw material availability, the manufacturing cost, the assembling and installation of the SP are some of the main decision factors for the optimized choice of material and dimensions. Although these factors have affected the selection of the studied cases, the results presented in the scope of this project have aimed to prove, in theory, the technical feasibility of the conception for deep and ultra-deep waters, without concern with the optimization of a specific configuration

(that would lead to a very peculiar interpretation of the obtained results).

Initially, the study comprised the numerical evaluation of the collapse envelope under combined external pressure and bending load (bending moment and curvature) for different SP configurations. The numerical simulations were carried out with the aid of a nonlinear finite element model incorporating finite plasticity and large rotations. Small-scale models of SP's filled with cement and polypropylene were manufactures and tested under hydrostatic pressure to determine the collapse pressure and the propagation pressure. The obtained results (see Table 1), where σ_{oi}, σ_{oe} mean the yielding stresses of the inner and outer pipes and P_{co} the collapse pressure, were useful to calibrate the numerical model developed, that can be used in the future as a design tool of sandwich pipe's for ultra-deep waters. Finally, a simplified comparative study of the structural performance under combined loading was carried out involving six different configurations of SP and corresponding single wall pipes (see Figure 2), where the table (a) represents the collapse pressures, the graph (b) the collapse envelopes and the table (c) the structural weights.

Besides the increase on the flexural rigidity, obtained

through the division of a single wall pipe in two cylindrical shells filled by an alternative material, sandwich pipe configurations are potential solutions for submarine layouts where the thermal insulation is a critical design parameter. The utilization of suitable core materials, which result in equivalent heat transfer coefficients capable to reduce the thermal loss between the mixture oil-gas-water and the environment, can make this conception technically very attractive.

Nevertheless, the evaluation of the required thermal insulation capacity of a pipe is highly dependent on the submarine layout studied (the flowing distances, the well flow, pressure, temperature, etc.). In addition, when thermal insulation requirements are established, the physical properties of the fluid exported (density, viscosity, thermal capacity, thermal conductivity, etc) must be correctly determined. The costs associated to manufacturing, installation, safety and operation are also important parameters to be considered during the design process.

In the research project, the problem was analyzed in a simplified manner under two different approaches. Initially, it was developed a parametric study to analyze the effect of different thickness and the thermal conductivity of the core

material on the global heat transfer coefficient obtained analytically. From the assumption that the global heat transfer coefficient required to avoid cooling of the fluid is known, the obtained results make possible to identify the PIP configurations that can attend the design requirements of thermal insulation. Next, it was carried out a theoretical analysis involving the thermal convection of the mixture oil-gas-water and thermal conductivity in the solid structure of the sandwich pipe. From the numerical solution of the state equations, it was possible to obtain the longitudinal temperature profile and to quantify the main design parameters in order to keep proper temperatures of the mixture along the pipeline.

As emphasized before, the study accomplished had no compromise with a specific sandwich pipe layout, since several combinations of material and geometric parameters can attend the same structural and thermal requirements. Nevertheless, the obtained results showed clearly a great potential for the employment of sandwich pipe systems for deep and ultra-deep waters, since it was verified its capacity to attend effectively and concomitantly both thermal and structural design requirements, with no major problems

related to operational or manufacturing processes, when compared to conventional pipelines.

Summary of the Invention

Finally, this invention is concerned with a sandwich pipe (SP), which consists of a multi-layer tubular rigid system, with the required capacity of thermal insulation and structural strength to be used for the transportation of warmed hydrocarbons in ultra-deep waters.

Detailed Description of the Invention

This invention describes a rigid system of cylindrical shape, with thermal functions and suitable mechanical strength to be installed in ultra-deep waters (beyond 1500 meters) and employed in the transportation of warmed hydrocarbons or other fluids. The invention comprises a composite system with three superposed layers, as described in Figure 1 (a), perspective view of the system, where **A** represents the external layer, **B** the intermediate layer and **C** the internal layer. The external and internal layers are pipes made of metallic alloys, such as the carbon steel, stainless steel, aluminum, titanium, etc. with or without seam (longitudinal weld). At the intermediate layer were considered cement or polypropylene, but may also be used ceramic materials, polymers or composite materials with low

thermal conductivity, high mechanical strength and good adherence with the internal and external pipes.

The drawings, tables and the data mentioned above, can not be considered as limitations to the scope of this invention, because it may be represented with more layers and/or different dimensions, depending on the conditions of utilization.

CLAIMS

1- "Sandwich Pipelines for Ultra-Deep Waters" comprised of a composite system with three or more superposed layers, characterized by one internal and external layer made of metallic alloys, such as carbon steel, stainless steel, aluminum, titanium, etc, and one intermediate layer made of cement, polypropylene, ceramic materials, polymers or composite materials with low thermal conductivity, high mechanical strength and good adherence with the internal and external pipes.

2- "Sandwich Pipelines for Ultra-Deep Waters" according to the claim 1, characterized by the utilization of carbon steel, preferably, in the manufacturing of the external and internal layers.

3- "Sandwich Pipelines for Ultra-Deep Waters" according to the claims 1 and 2, characterized by the utilization of cement, preferably, in the manufacturing of the intermediate layer.

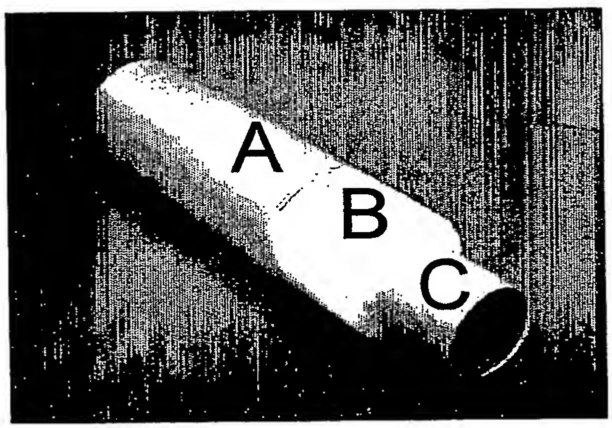
4- "Sandwich Pipelines for Ultra-Deep Waters" according to the claims 1 and 2, characterized by the utilization of polypropylene, preferably, in the manufacturing of the intermediate layer.

5- "Sandwich Pipelines for Ultra-Deep Waters",

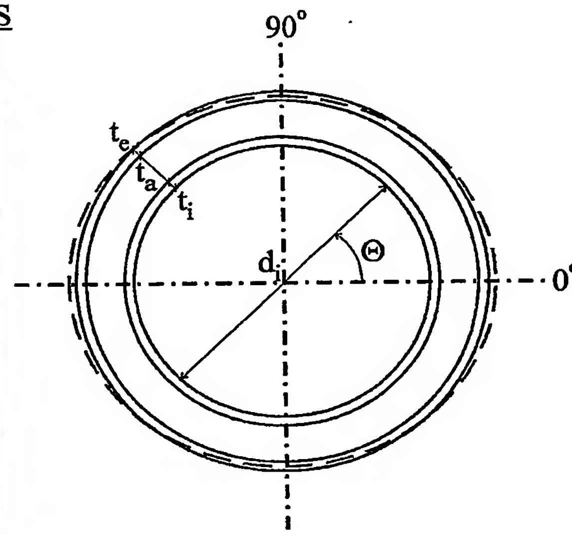
characterized by the utilization for the transportation of warmed hydrocarbons or fluids in ultra-deep waters.

6- "Sandwich Pipelines for Ultra-Deep Waters" according to the claim 1, characterized by attending concomitantly both the basic design requirements of mechanical strength and thermal insulation.

FIGURES



(a)



(b)

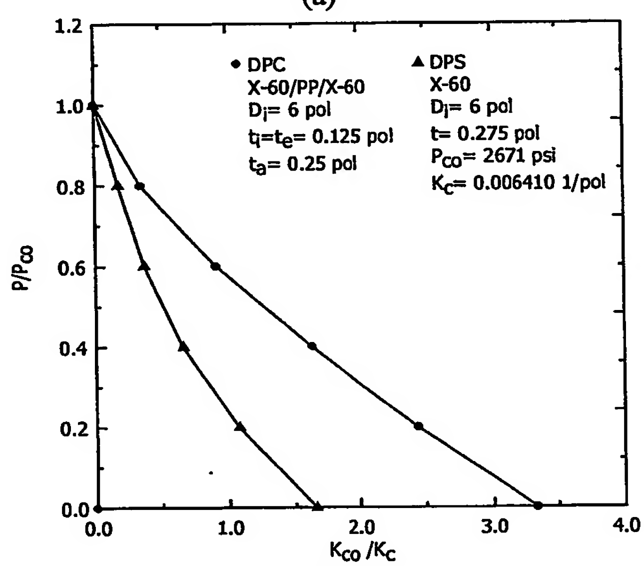
Figure 1

D_i (mm)	t_i (mm)	σ_{oi} (MPa)	t_e (mm)	σ_{oe} (MPa)	t_a (mm)	P_{co} (Mpa)
45.91	1.62	199.79	1.62	200.93	11.29	43.35
47.10	1.63	195.20	1.65	192.10	11.13	34.09
47.40	1.68	180.71	1.47	141.57	4.23	10.98
47.37	1.67	180.71	1.47	141.57	4.30	12.11
46.28	1.68	186.82	1.62	206.52	11.26	37.64
46.52	1.62	194.37	1.61	206.52	11.10	31.14
46.54	1.70	186.82	1.46	141.57	4.62	20.31
46.65	1.69	186.82	1.49	160.37	4.69	17.13

Table 1

DPC					DPS		
D_i(pol)	t_i, t_e(pol)	t_a(pol)	Anular	P_{co}(psi)	D_i(pol)	t(pol)	D/t
6.0	0.125	0.25	PP	2628	6.0	0.275	23.8
			CMT	4172	6.0	0.350	19.1
6.0	0.1875	0.75	PP	5341	6.0	0.405	16.8
			CMT	8267	6.0	0.545	13.0
6.0	0.25	1.25	PP	7692	6.0	0.520	13.5
			CMT	12324	6.0	0.740	10.1

(a)



(b)

DPC						DPS		
t_i, t_e(pol)	t_a(pol)	Anular	P_a (lb/pé)	P_{tot} (lb/pé)	P_{sub} (lb/pé)	t (pol)	P_a,P_{tot} (lb/pé)	P_{sub} (lb/pé)
0.125	0.25	PP	17.371	19.385	2.286	0.275	18.447	3.475
		CMT		21.187	4.087	0.350	23.759	8.094
0.1875	0.75	PP	28.563	35.185	11.433	0.405	27.731	11.547
		CMT		41.109	17.357	0.545	38.133	20.590
0.25	1.25	PP	41.425	53.430	21.936	0.520	36.244	18.949
		CMT		64.169	32.675	0.740	53.319	33.794

(c)

Figure 2

INTERNATIONAL SEARCH REPORT

International application No.
PCT/BR 02/00136-0

A. CLASSIFICATION OF SUBJECT MATTER

IPC[7]: F16L 9/147, 9/153

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC[7]: F16L 9/14, 9/147, 9/153, 9/18

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WPI, EPODOC, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5755265 A (STOUTEN) 26 May 1998 (26.05.98) *abstract, column 2, line 66 - column 3, line 11, fig. 1,2.*	1
A	WO 96/02785 A1 (WINN & CO. ALES INTERNATIONAL LTD.) 1 February 1996 (01.02.96) *abstract, fig. 1.*	1

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:

„A" document defining the general state of the art which is not considered to be of particular relevance

„E" earlier application or patent but published on or after the international filing date

„L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

„O" document referring to an oral disclosure, use, exhibition or other means

„P" document published prior to the international filing date but later than the priority date claimed

„T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

„X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

„Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

„&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
12 February 2003 (12.02.2003)	3 March 2003 (03.03.2003)

Name and mailing adress of the ISA/AT	Authorized officer
Austrian Patent Office Kohlmarkt 8-10; A-1014 Vienna Facsimile No. 1/53424/535	ENDLER E. Telephone No. 1/53424/423

INTERNATION[redacted]EARCH REPORT
Information on [redacted]t family members

International [redacted] application No.
PCT[redacted]02/00136-0

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				AP	A	554	06-11-1996
				NZ	A	289188	26-05-1997
				ZA	A	9505739	21-02-1996